Max Planck Institute for Gravitational Physics
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Interferometric characterization of the optical window for LISA and LISA Pathfinder

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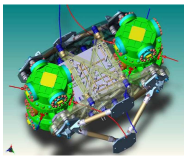
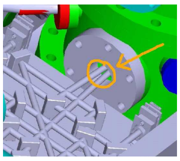
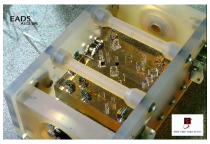
Introduction

LISA Pathfinder (LPF) is a technology demonstration mission of ESA and NASA to be launched in 2009. Its main goal is the demonstration of the drag free fall of two test masses to a level of $3\text{x}10^{-14}\,\mathrm{m\cdot s^{-2}/\sqrt{Hz}}$





A set of 4 heterodyne Mach-Zehnder interferometers is bonded on top of an optical bench (OB) between the two test masses to monitor their position fluctuations with picometer precision. In the engineering model (EM) of the OB, the test masses have been replaced by mirrors and the required sensitivity for the interferometer+phasemeter system ($10\,\mathrm{pm/\sqrt{Hz}}$ at 1 mHz) has been demonstrated.



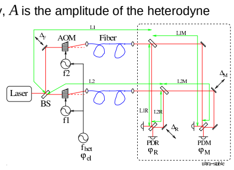
LPF interferometer: principle of function

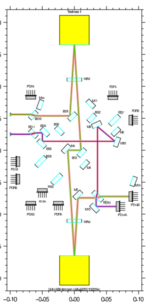
The laser beam is split into two parts. Each beam is then frequency shifted by an AOM (acousto-optic modulator) in the modulation bench. The two beams are brought to interference on an ultrastable optical bench. The interference signal measured at a photodetector is given by:

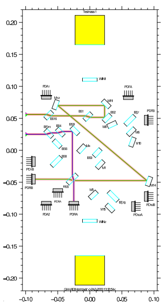
$$I(\varphi)=A\cdot(1-c\cdot\cos(\varphi))$$

where I is the measured intensity, A is the amplitude of the heterodyne signal, c is the contrast and φ is the phase of the heterodyne signal which varies with the displacement ΔL of the test masses as follows:

$$\varphi=2\pi\cdot f_{het}\cdot t+\frac{2\pi\cdot\Delta L}{\lambda}$$







Optical layout of the Reference interferometer and the interferometer that measures the distance fluctuations between the two test masses. Note optical windows in front of test masses.

Glass selection for the optical window:

Main noise sources :

- Thermal variation of optical pathlength.
- Mechanical motion of the window in z-direction.
- Stress-induced change in refractive index and optical pathlength.
- Mechanical tilt fluctuations of the window.

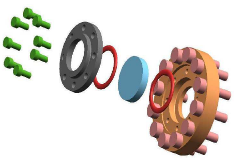
The sum of all noise contributions of one window (in double pass) is counted as one interferometer noise source and allocated a budget of $1\,\mathrm{pm/\sqrt{Hz}}$

Thermal variations of the optical pathlength (Δs) are given by:
Δs = ΔT × L × (dn/dT + (n − 1)**α**)
The best candidate identified so far is **Ohara S-PHM52.**
The selection criteria for the glass is the minimization of (dn/dT + (n − 1)**α**)
(At 1064 nm (dn/dT + (n − 1)**α**) = 0.59 ppm/K).

Optical Window prototype

Three optical window (OW) prototypes have been manufactured by Carlo Gavacci Space. They are composed by:

- CF 40 Flange
- Titanium cover
- 2 helicoflex seals.
- Ohara S-PHM52

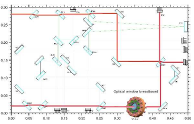


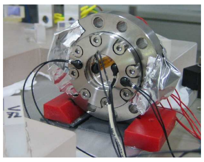
Thermal characterization

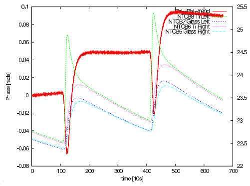
The objective of this measurements is the characterization of the pathlength variations induced in the OW prototype by temperature fluctuations and then derive the temperature stability corresponding to the allocated pathlength noise of $1\,\mathrm{pm/\sqrt{Hz}}$ at 1 mHz.

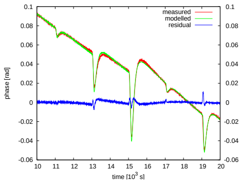
Set-up:

Each breadboard was mounted on an ULE optical bench as a transmissive element. Four NTC temperature sensor and three heaters were fixed to the OW. Temperature steps were applied to the OW while all temperature signals and interferometer output phase were monitored.









The interferometric phase is fitted to the model (after detrend):

$$\varphi=p_3\frac{T_{Ti_1}+T_{Ti_2}}{2}+p_4\frac{T_{Gl_1}+T_{Gl_2}}{2}$$

with

T_{Ti_1} and T_{Ti_2} metal temperature

T_{Gl_1} and T_{Gl_2} glass temperature

Results:

p_3 = 0.09 ± 0.01 rad/K

p_4 = - 0.07 ± 0.01 rad/K

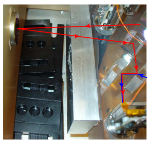
Required thermal stability of $1.2\times10^{-5}\,\mathrm{K/\sqrt{Hz}}$ in the measurement band.

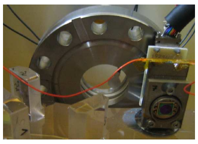
Long-term performance

The long-term behavior of the OW was tested with the EM of the LTP interferometer. The aim of the measurement is to investigate an eventual degradation of the interferometric readout performance when the OW is present in the beam path.

LTP-like experimental set-up:

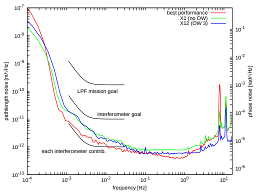
The breadboard is attached to the side of the optical bench plate in front of the dummy mirror that acts as TM2. The readout of the TM1 position fluctuations is an independent indicator of the interferometric performance. Three of the tested OW prototypes have AR coated glass (to investigate mechanical stress induced by the AR coating) and have undergone different environmental testing (leak testing, random vibration and thermal cycling).





Results:

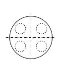
Several performance measurements have been done on each OW sample. A typical result shows the performance of the X12 interferometer (where a OW prototype has been placed in front of the dummy mirror acting as test mass) and the performance of the X1 interferometer (without OW). There is also a third curve showing the best performance measured with the EM .



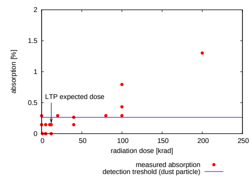
No degradation of the interferometric performance due to any OW prototype detected. Settling effects from the environmental testing or stress effects induced by AR coating can be discarded.

Radiation tests

The expected deposited radiation on the LTP OW is 12 krad. Four glass samples were exposed to a radiation dose going from 1 krad to 200 krad (4 spots per sample) using a proton beam of 30 MeV.



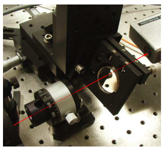
The OW were tilted with respect to the incoming beam to avoid parasitic ethalon effects. The measured absorption remains under 1.4% and sets an upper limit for the actual one.



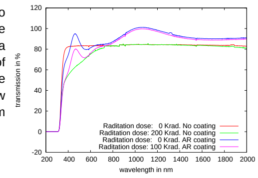
Absorption measurements

Two different approaches have been followed to quantify the absorption in the radiated samples:

1) Glass sample is placed in a XY translation stage. Using a 1064 nm NPRO laser similar to the LTP one, the relative transmission of the radiated spots is evaluated.



2) Transmission was also measured in dependence of the wavelength with a spectrometer. Spectra of both AR coated and one uncoated samples show absorption from 800 nm down to UV.



Conclusions

- Thermal effects well studied and understood
- Realistic test in the EM OB show no degradation of the interferometer performance
- Radiation test show no significant increase in absorption
- We do have a window!

Bibliography:

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